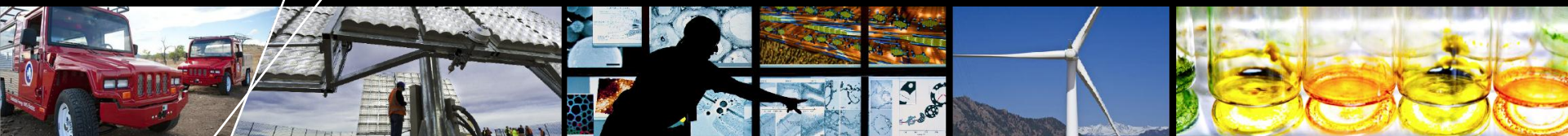


Innovation: Enabling a Sustainable Energy Future



Dr. Dan E. Arvizu

Laboratory Director

SunShot Summit

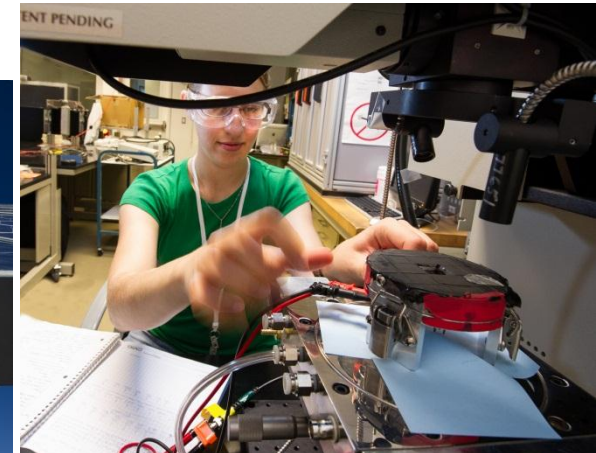
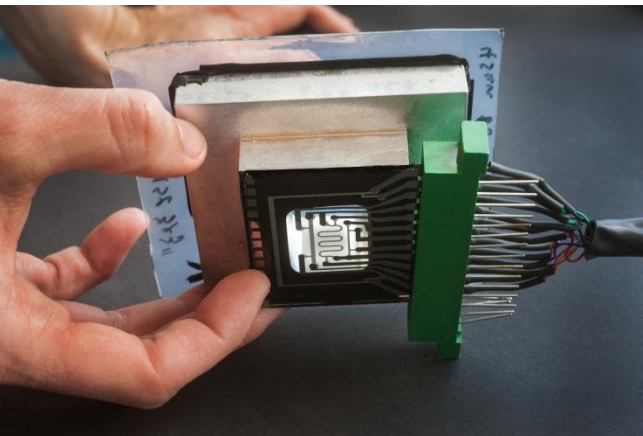
May 21, 2014



NREL Supports SunShot



Our scientists are pursuing critical activities that will help to accomplish the goal of the U.S. Department of Energy's SunShot Initiative—to make large-scale solar energy systems cost-competitive with other energy sources by 2020.



Energy Market Dynamics

Global renewable industry growing, still faces challenges

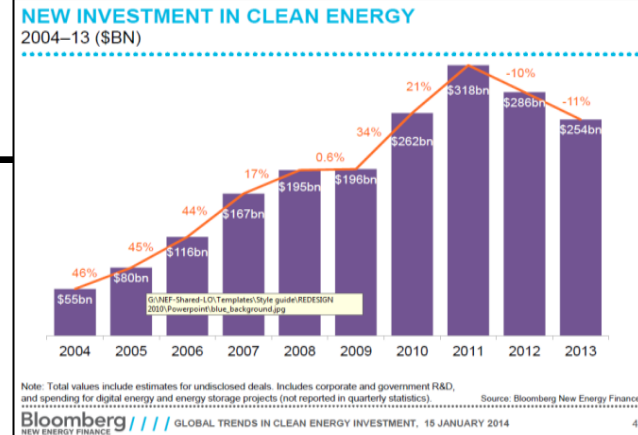
Public policy evolving

Effects of Great Recession still evident

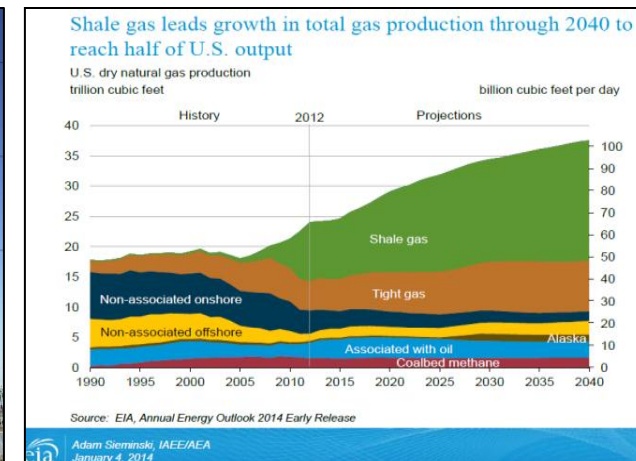
Shale gas a growing focus in U.S. and elsewhere

Infrastructure investments will be made, must focus on flexibility

Rev 5/14/14



<http://www.imf.org/external/pubs/ft/weo/2014/update/01/index.htm>



A Profound Transformation is Required

Today's Unsustainable Energy System

Future Sustainable Energy System



TRANSFORMATION

- Limited fuel diversity
- Subject to price volatility
- Inefficient and rigid
- Significant carbon emissions
- Delivery systems vulnerable
- Aging infrastructure

- Diverse supply options
- Affordable, stable and reliable
- Efficient and flexible
- Carbon neutral
- Secure and resilient
- Engine for innovation

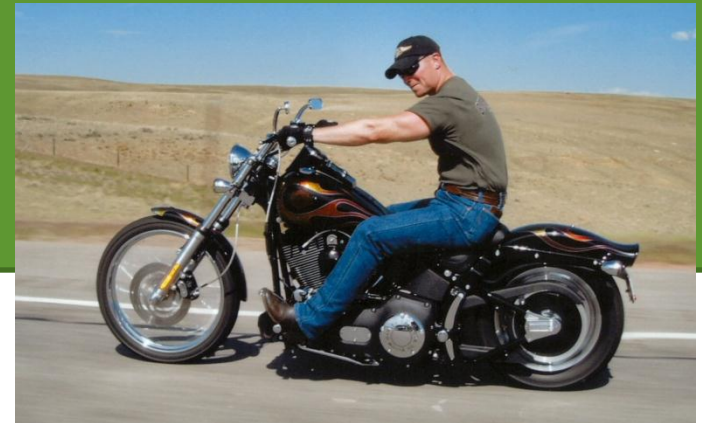
1/13/2014

Change is Hard

“Facts are important but not sufficient to change human behavior.”

—Dr. Arthur Caplan, Bioethicist

2014 National Science Board Award
Winner for Public Service



Smoking causes cancer.

Riding without a helmet is dangerous.

Vaccinations prevent disease and death.



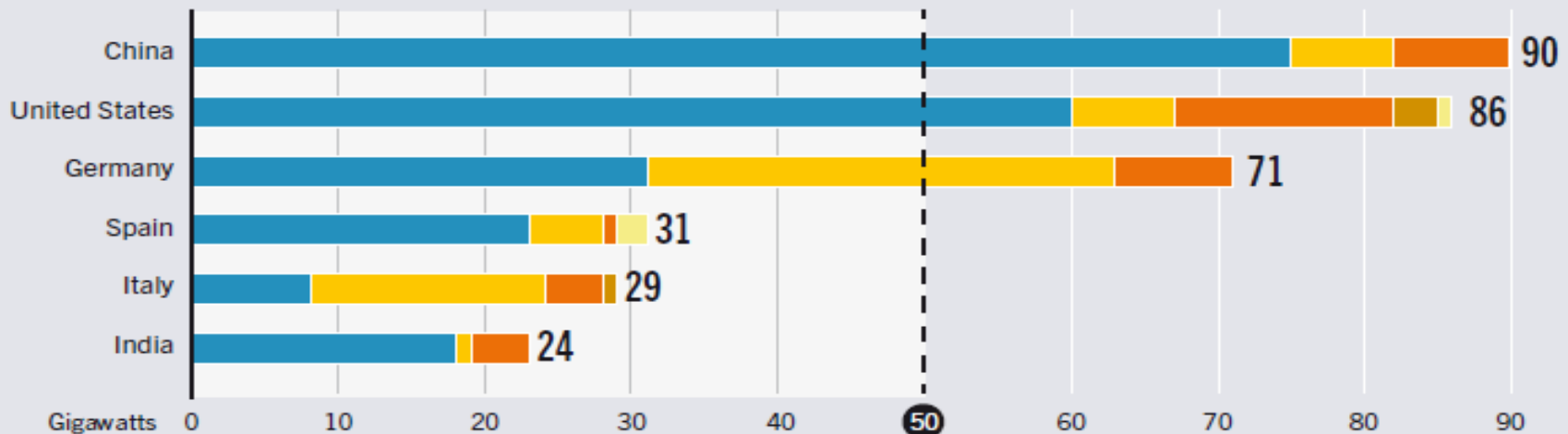
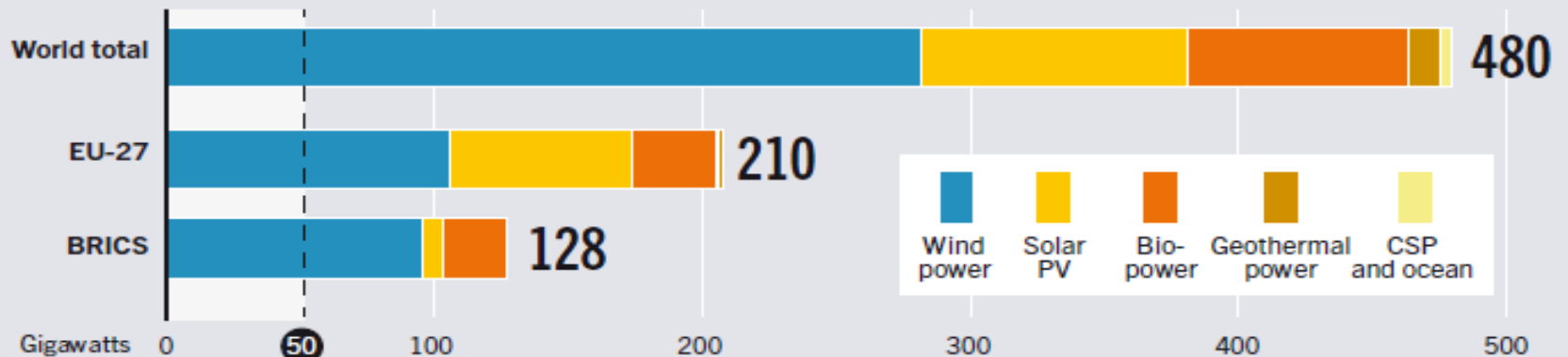
Transition to a Sustainable Energy Economy

What will compel a transition? *Addressing the three myths....*

- You don't have to go without. *No sacrifice required.*
- You can still have choice. *Choices are enhanced.*
- Pace matters; there are consequences for not acting now. *Security, cost and competitiveness, and environmental quality.*

Worldwide Renewable Capacity

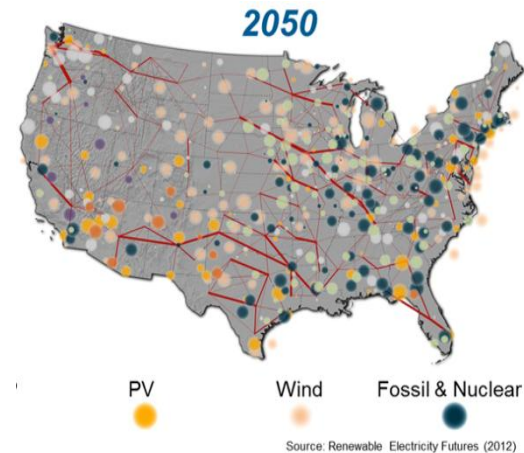
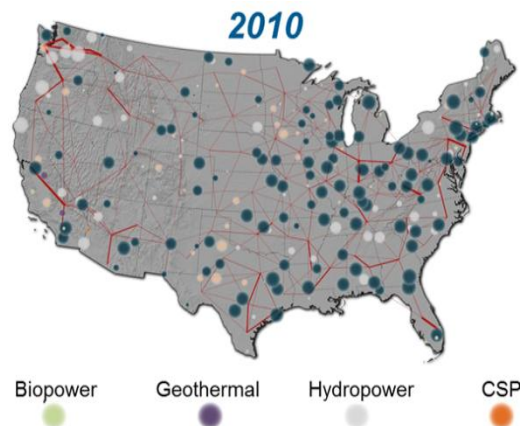
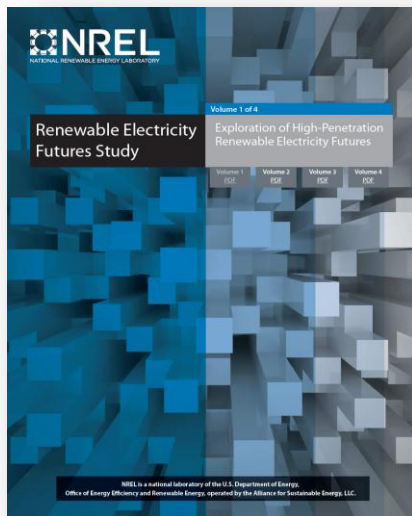
RENEWABLE POWER CAPACITIES* IN WORLD, EU-27, BRICS, AND TOP SIX COUNTRIES, 2012



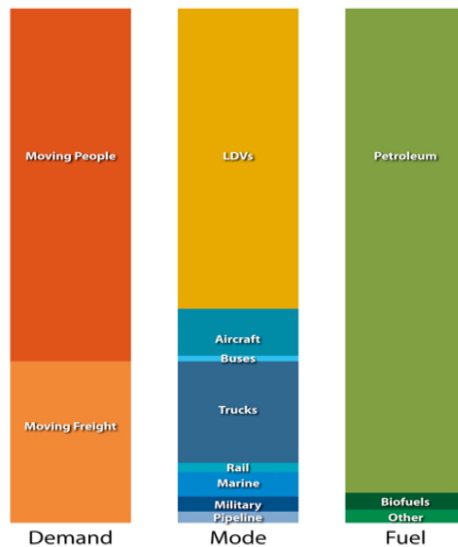
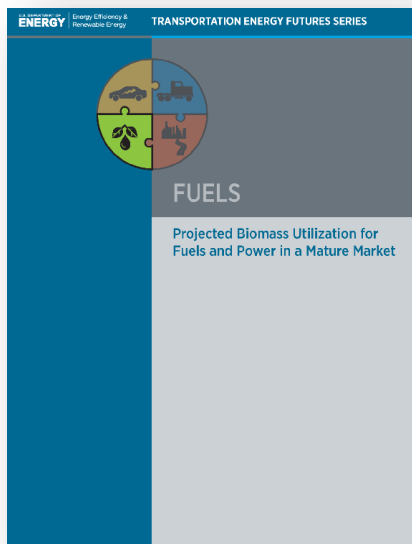
*not including hydropower

Source REN21 Renewables 2013 Status Report

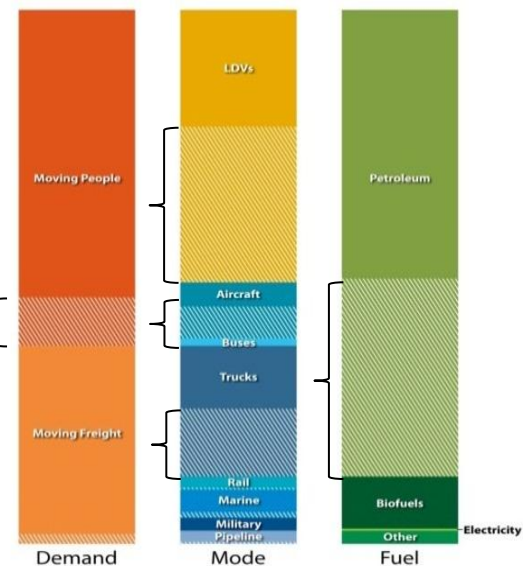
Comprehensive Studies Validate Opportunity for U.S. Renewables



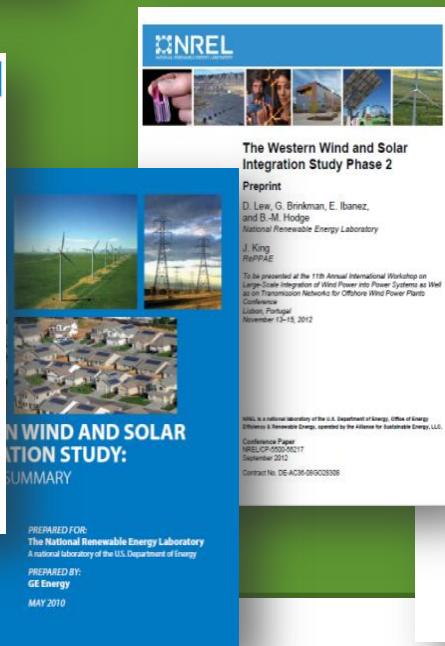
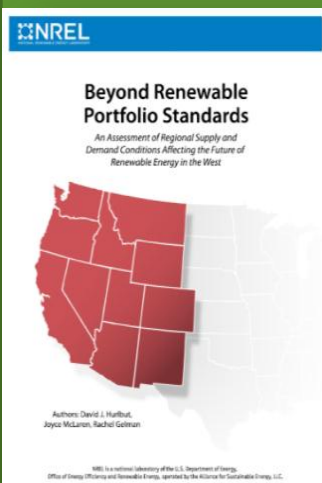
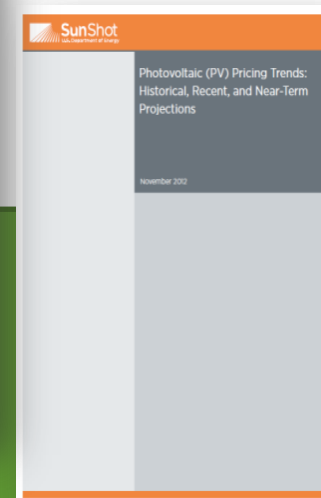
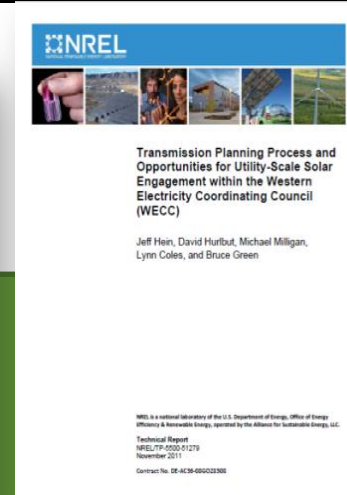
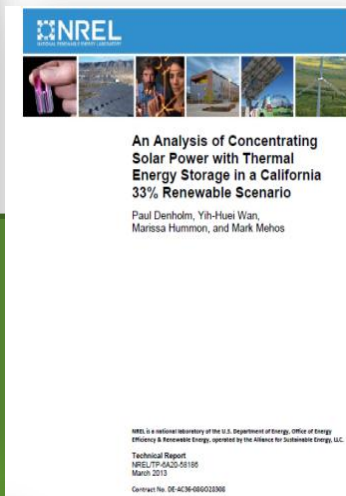
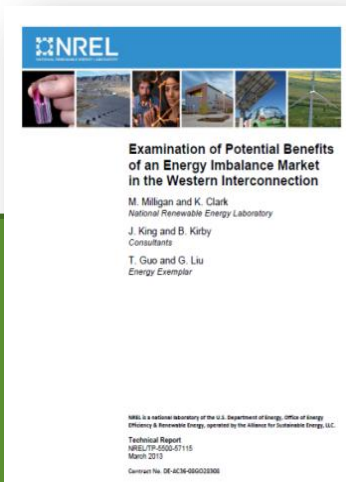
Source: Renewable Electricity Futures (2012)



Potential cost savings



Looking Toward Implementation



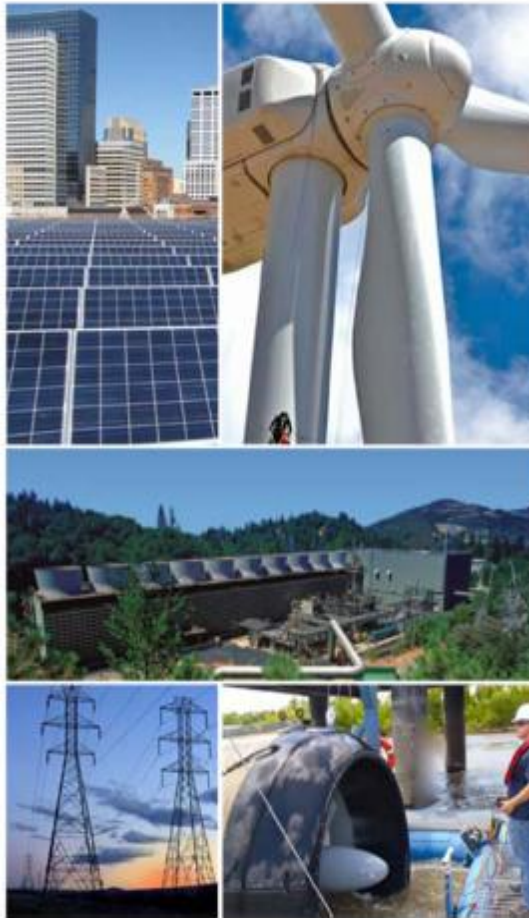
Benefits of distributed generation
Economics of technical pathways
Implications of high penetration renewables
Value of regional cooperation

Technology Innovation

Sustainable TRANSPORTATION



Renewable ELECTRICITY GENERATION



Energy Saving HOMES, BUILDINGS, & MANUFACTURING



Solar Electricity: *State of the Technology*



Photovoltaics (PV)

- Market: Residential; Commercial, Utility
- Geographically diverse
- kW to MW to GWs
- U.S. Capacity: 12.1 GW
- U.S. Forecast: 40+ GWs in pipeline
- Costs: <\$2 to \$6/W: *LCOE 7 to 16¢/kWh
- Technologies: Conversion; thin-films, crystalline silicon. Storage; battery

*With federal incentives, e.g., the FTC.



Solar Thermal Electric (CSP)

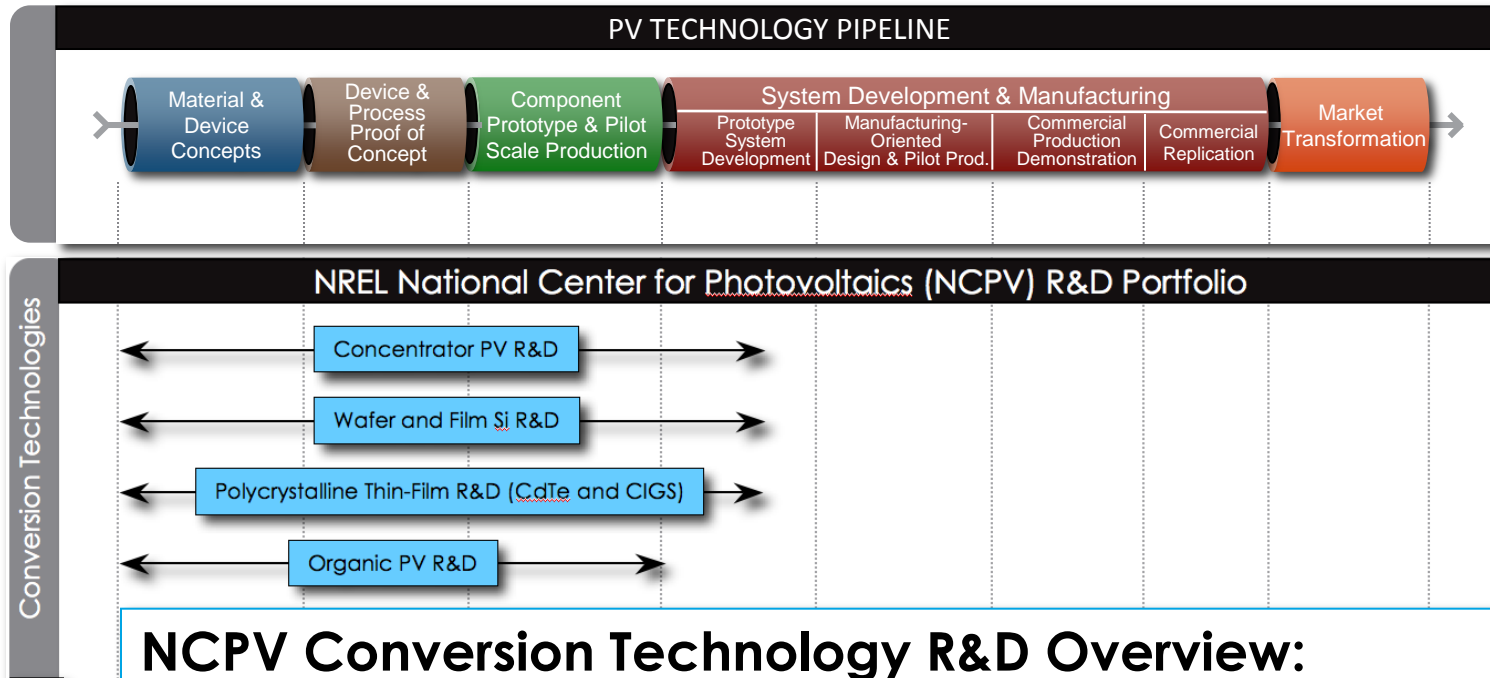
- Market: Commercial; Utility
- Geographically confined to “sun bowls”
- MWs to GWs
- U.S. Capacity: 1186 MW at year end 2013, 672 MW installed in 2013, 640 MW under construction in 2014
- U.S. Forecast: 3.5 GWs in pipeline
- Costs: \$4 to \$8/W[†]: *LCOE 12 to 16¢/kWh
- Technologies: Conversion; parabolic troughs, central receivers, linear Fresnel, dish. Storage; thermal, up to 15 hours.

[†]Dependent on storage capacity

Updated: May 2014

Source: GTM/SEIA : U.S. Solar Market Insight 2011 - 2013 Year-in-Review

NCPV Conversion Technology R&D Portfolio

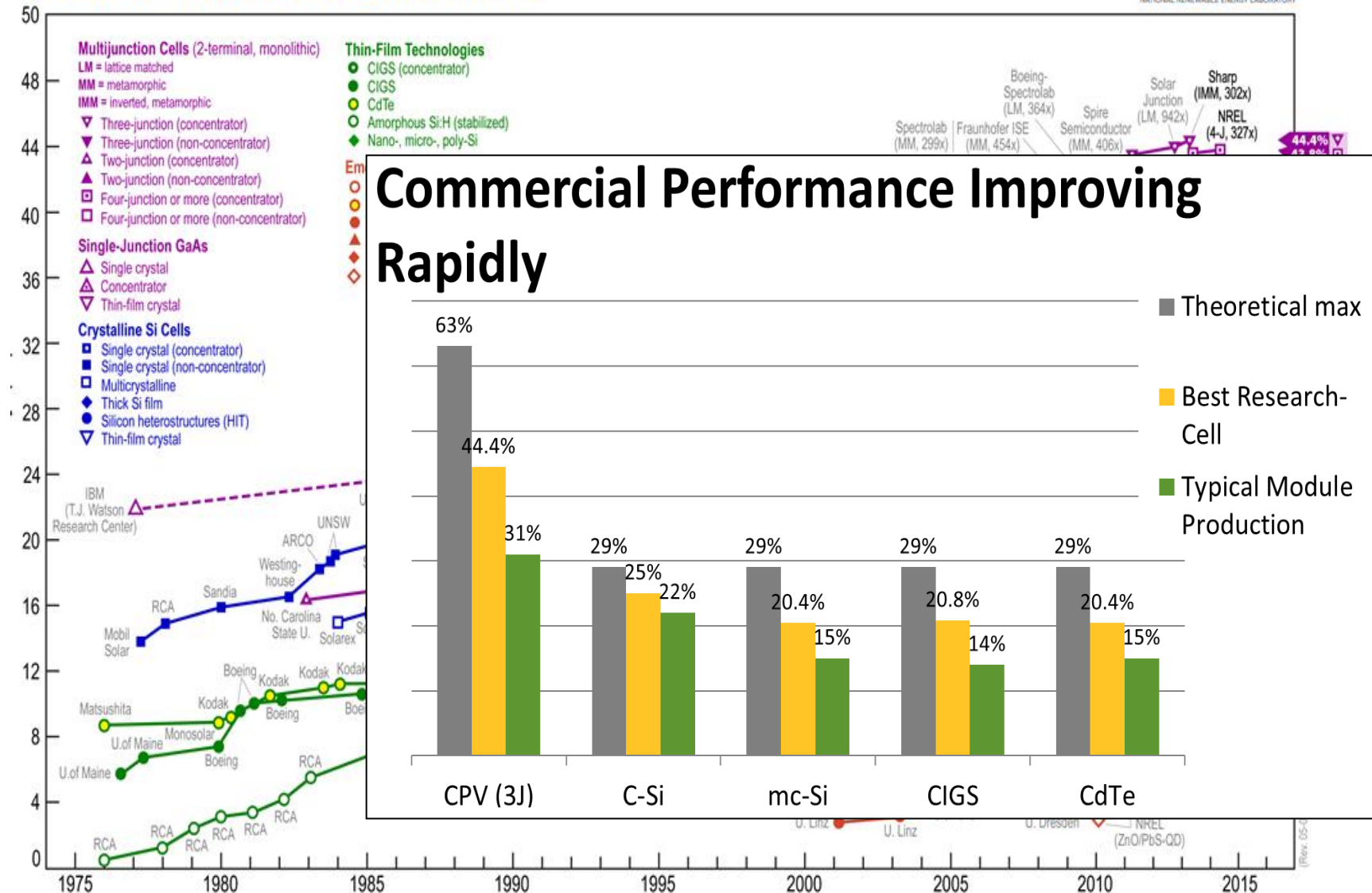


NCPV Conversion Technology R&D Overview:

- ➔ III-V Multijunction Highest potential η , > 50%
- ➔ Wafer Si Most common technology, ~25% 1-J η today
- ➔ Thin Si Potential for low cost and > 20% η
- ➔ CdTe Lowest cost in HVM today, potential for > 20% η
- ➔ CIGS Can be flexible, potential for > 20% η
- ➔ Organic PV (OPV) Flexible, potentially very low cost

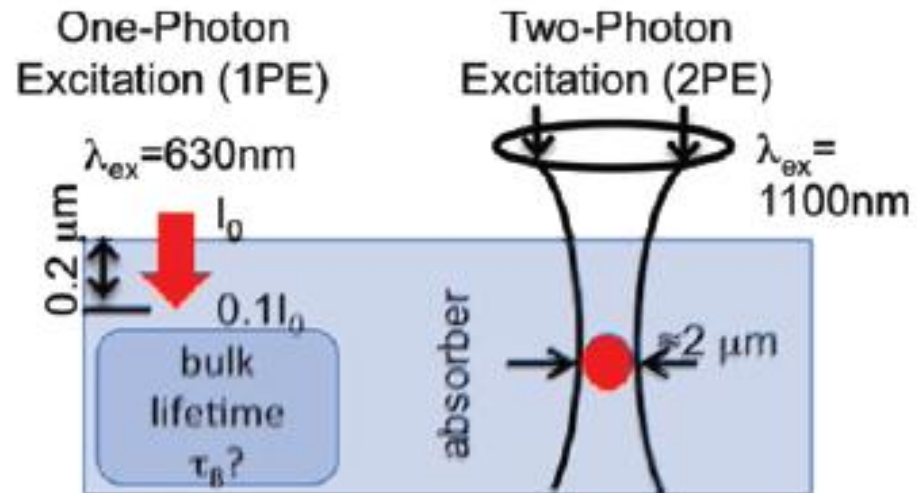
PV Research—Significant Innovation Space

Best Research-Cell Efficiencies



Technique Reveals Critical Physics in Deep Regions of Solar Cells

NREL's improved time-resolved photoluminescence method measures minority-carrier lifetime deep within photovoltaic samples to help develop more efficient solar cells.



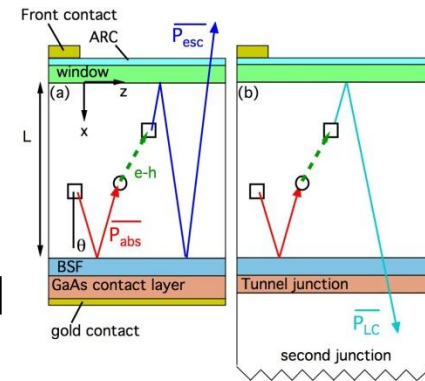
Using two-photon excitation (right side), light is absorbed in the laser-beam focus region, which can be either at the sample surface or in the bulk.

Recent NREL Solar Cell Records

III-V multijunctions:

31.1% one-sun record for two junctions

34.1% (467 suns) concentrator two junction record



NREL model of internal cell optics guides development of world record cells

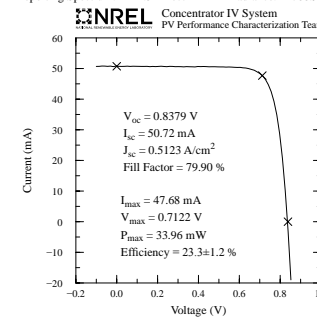
CIGS:

23.3% (15 suns) CIGS concentrator record

20.65% (near the 20.9% record)

NREL
CdS/Cu(In,Ga)Se₂ Cell

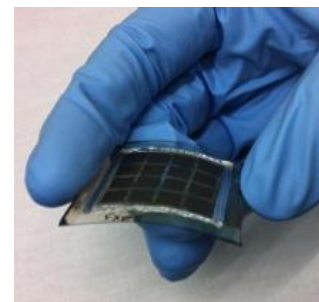
Device ID: C3598-22N7a Device Temperature: 25.0 ± 1.0 °C
Mon, Mar 10, 2014 1:04 PM Device Area: 0.09902 cm²
Reporting Spectrum: AM1.5 Direct Irradiance: 14706.9 W/m²



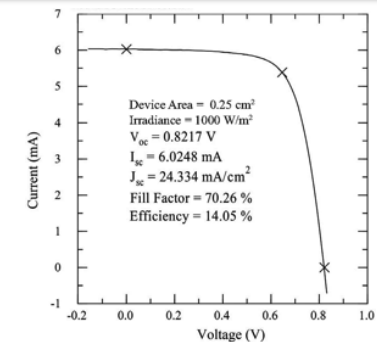
Record CIGS concentrator cell

CdTe:

14.05% record for flexible CdTe cell



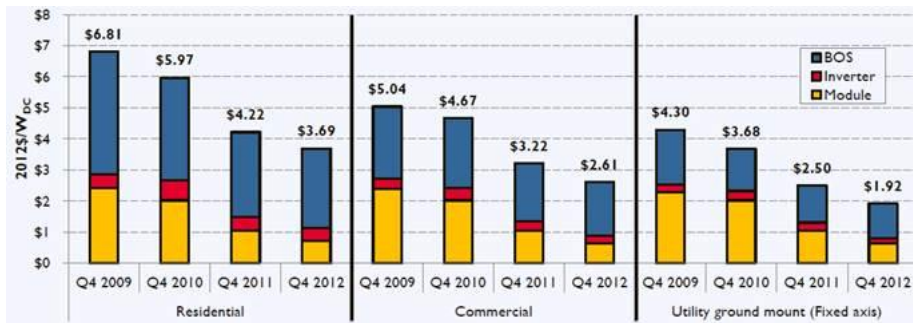
Record flexible CdTe cell



Solar Manufacturing and Systems Cost Analysis

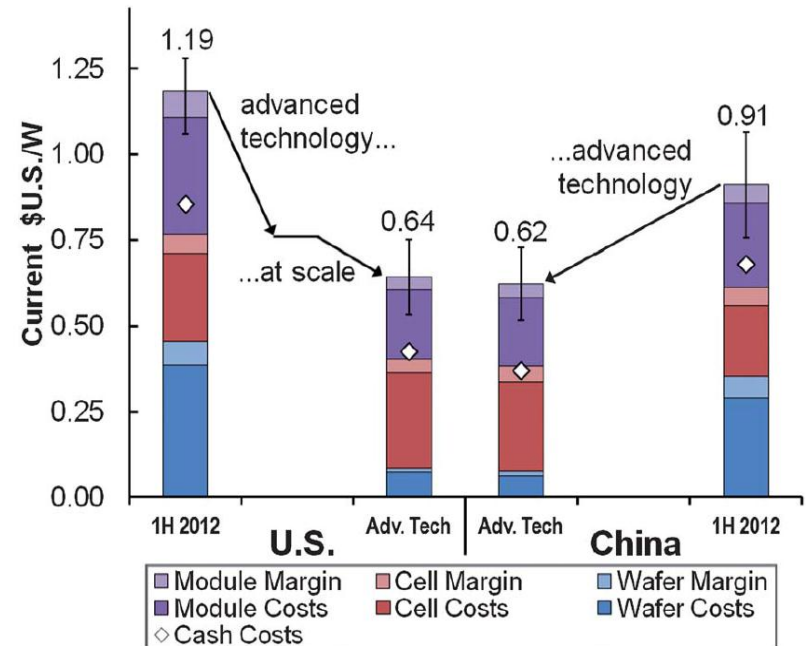
- Benchmark the cost of solar techs, evaluate the range of technical pathways being pursued, and reallocate R&D resources as necessary
- Evaluate technical improvements opportunities through detailed cost modeling
- Enhance understanding of the economic competitiveness of solar technologies and manufacturing locations.

System Installation Costs Analysis and Roadmapping



Modeled (Bottoms-Up) PV System Prices by Sector (2009-2012).

U.S. Competitiveness

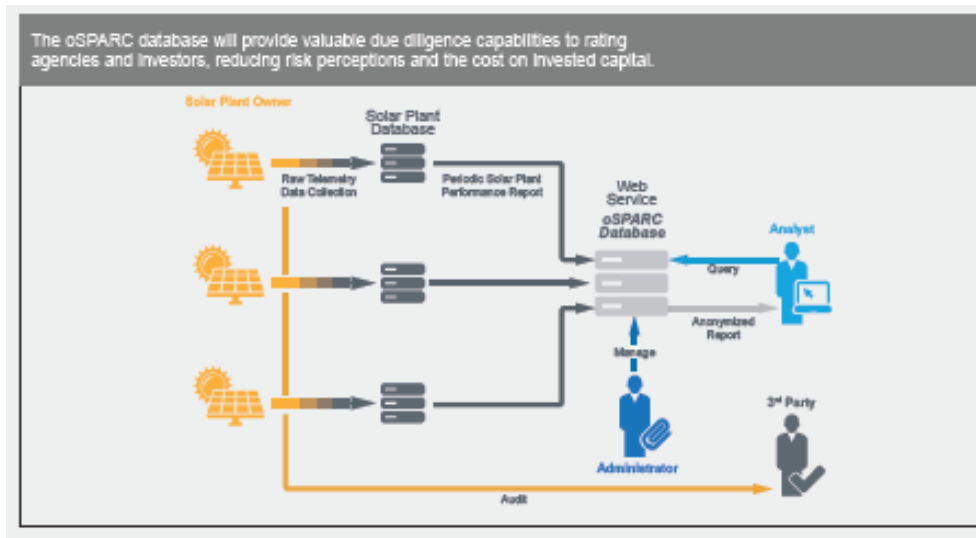


Advanced Financing to Achieve SunShot Goals

The Advanced Financing to Achieve Sunshot project seeks to expand the availability and lower the cost of capital to deploy solar in the United States.

FY13-15: NREL has assembled two working groups to perform its tasks under the DOE award.

- The Solar Access to Public Capital (SAPC) group facilitates solar securitization and opens the capital markets to the solar asset class.
- The Banking on Solar group increases the availability of loan products in the residential and commercial solar areas.



Next Steps:

- Standardize contract terms and documents
- Build endorsement among developers.
- Engage broader investment community.
- Expand mock securitization to commercial portfolio.
- Standardize loan document and develop education materials.

NREL Mission Focus

| Energy Efficiency | Renewable Energy | Systems Integration | Market Focus |
|--|---|--|--|
| Residential Buildings Commercial Buildings Personal and Commercial Vehicles | Solar Wind and Water Biomass Hydrogen Geothermal | Grid Infrastructure Distributed Energy Interconnection Battery and Thermal Storage Transportation | Private Industry Federal Agencies State/Local Govt. International |

The New Frontiers: Integration and Scale

- Integration of high-penetration renewables requires enhanced system-wide flexibility
 - Variable supply and variable load
 - Increased distributed resources
 - Enhanced energy imbalance market cooperation
 - Changing roles of consumers, utilities, investors, power providers, vendors, and regulators
- Regional considerations continue to drive progress
- Production scale and supply chain crucial to lower manufacturing costs
- Investment in technology R&D imperative
 - Better monitoring and measurements
 - Advanced analytics processing and control
 - Demand-shifting and load profile shaping techniques
 - Two way power flow control electronics



Innovation, Integration and Adoption

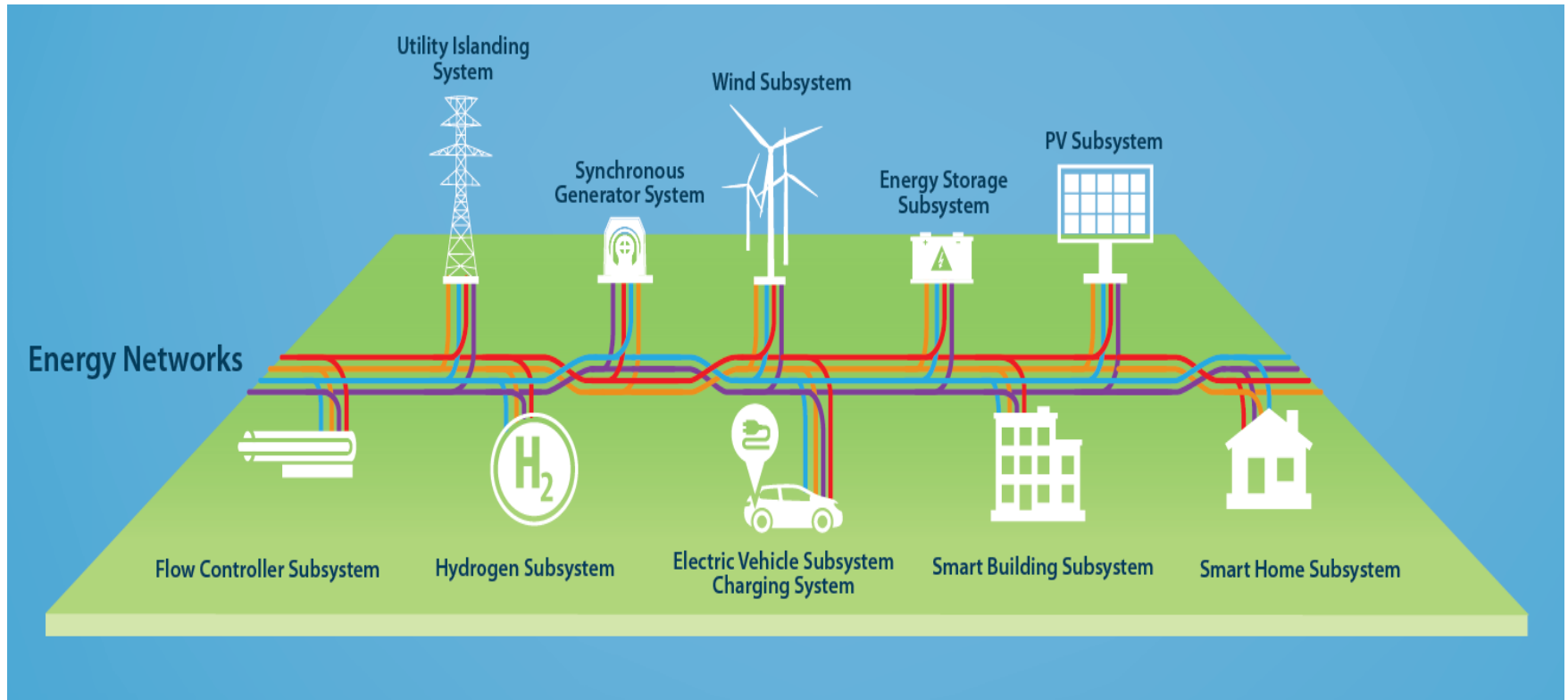
Reducing Investment Risk

- Enable basic and applied clean energy technology innovation
- Accelerate technology market introduction and adoption
- Integrate technology at scale
- Encourage collaboration in unique research and testing “partnering” facilities



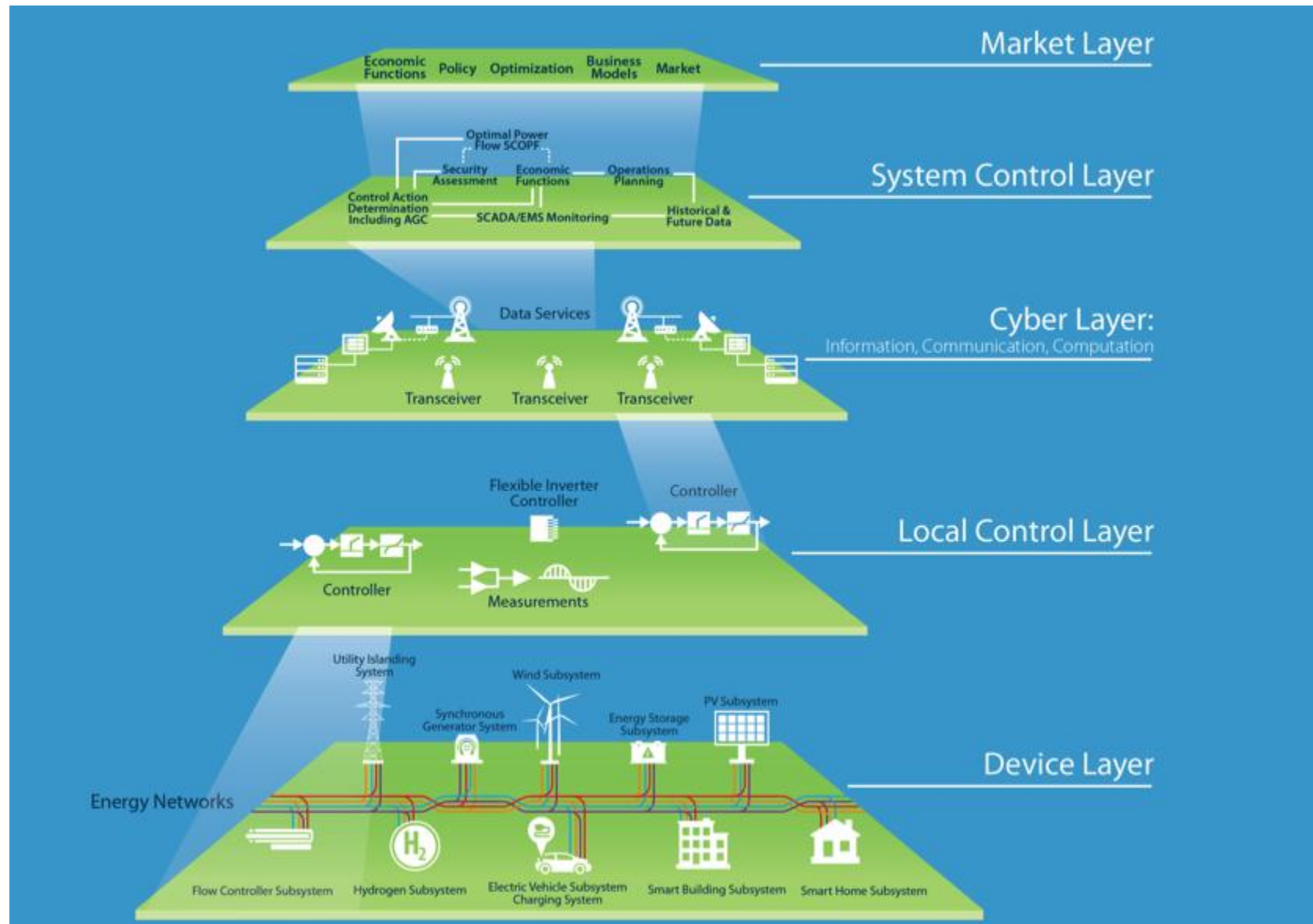
Mobilizing Capital

Integrate Technologies Into System



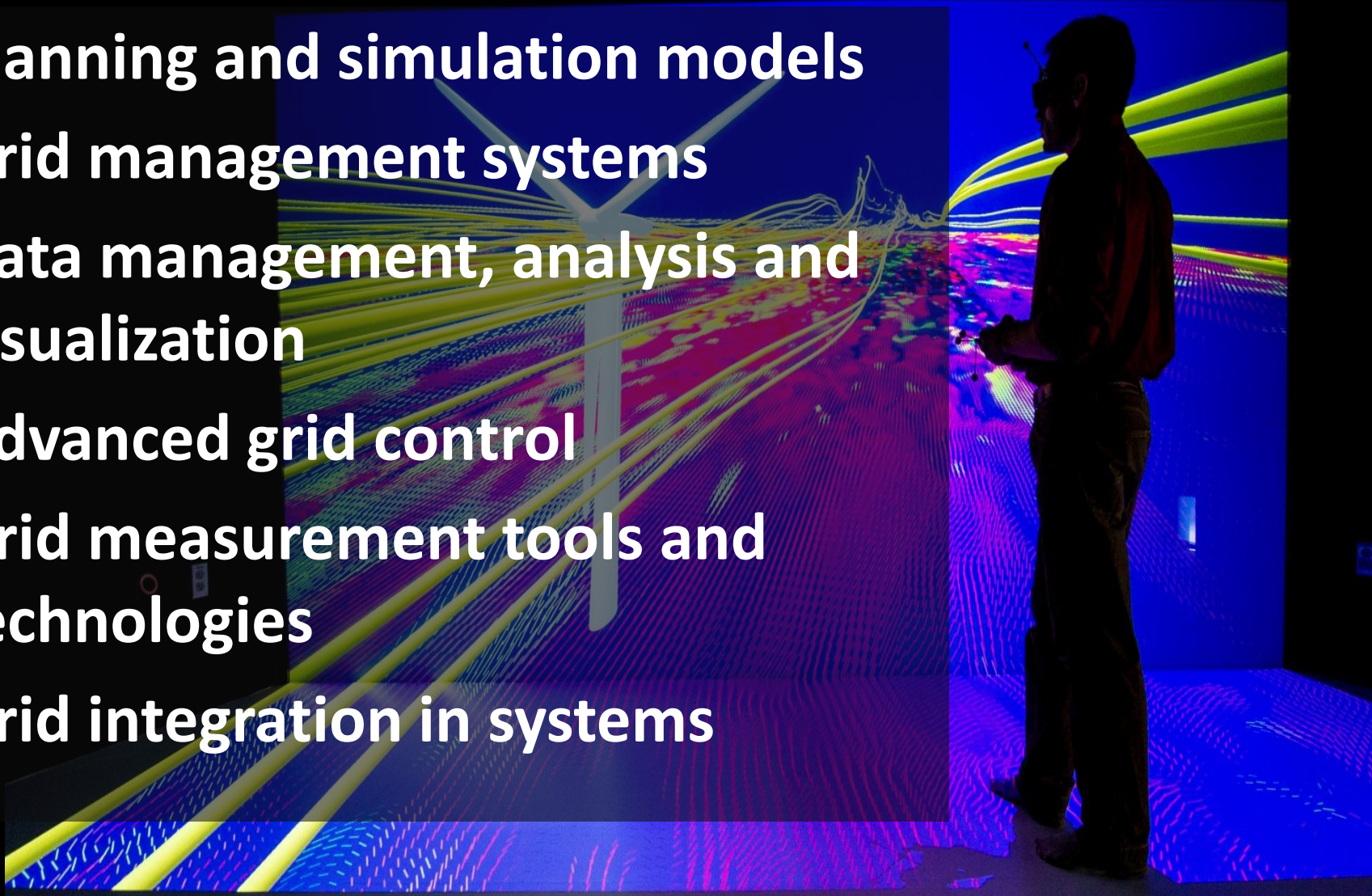
Characterize and predict how components and devices will interact with the others in the system

Integrate Across Functional Layers



Systems Integration R&D Agenda

- Planning and simulation models
- Grid management systems
- Data management, analysis and visualization
- Advanced grid control
- Grid measurement tools and technologies
- Grid integration in systems



Engaging Industry



Energy Systems
Integration

HPC Cooling
Thermal and optical performance
Electric vehicles
Green Hydrogen
Military apps
Control algorithms
Residential scale up
Storage systems

HOUZE®
THE POWER OF ZERO

ASETEK
DATA CENTER LIQUID COOLING

ΔE ADVANCED
ENERGY®

 **TOYOTA**

ABENGOA
Innovative technology solutions for sustainability



 **SOLECTRIA**
RENEWABLES

SPI
SOLAR POWER INC

wyle

EPRI | ELECTRIC POWER
RESEARCH INSTITUTE

TECHNOLOGY ADDRESSED

Solar inverter controls validation for high penetration utility and commercial photovoltaics (PV).

R&D STRATEGY

Demonstrate 500 kW PV inverter performance by connecting the inverter to NREL's megawatt scale grid simulators, PV simulators, load banks and real-time electric distribution feeder models.

IMPACT

Increase PV saturation without negatively impacting the distribution grid through modifying the behaviors of inverters.



TECHNOLOGY ADDRESSED

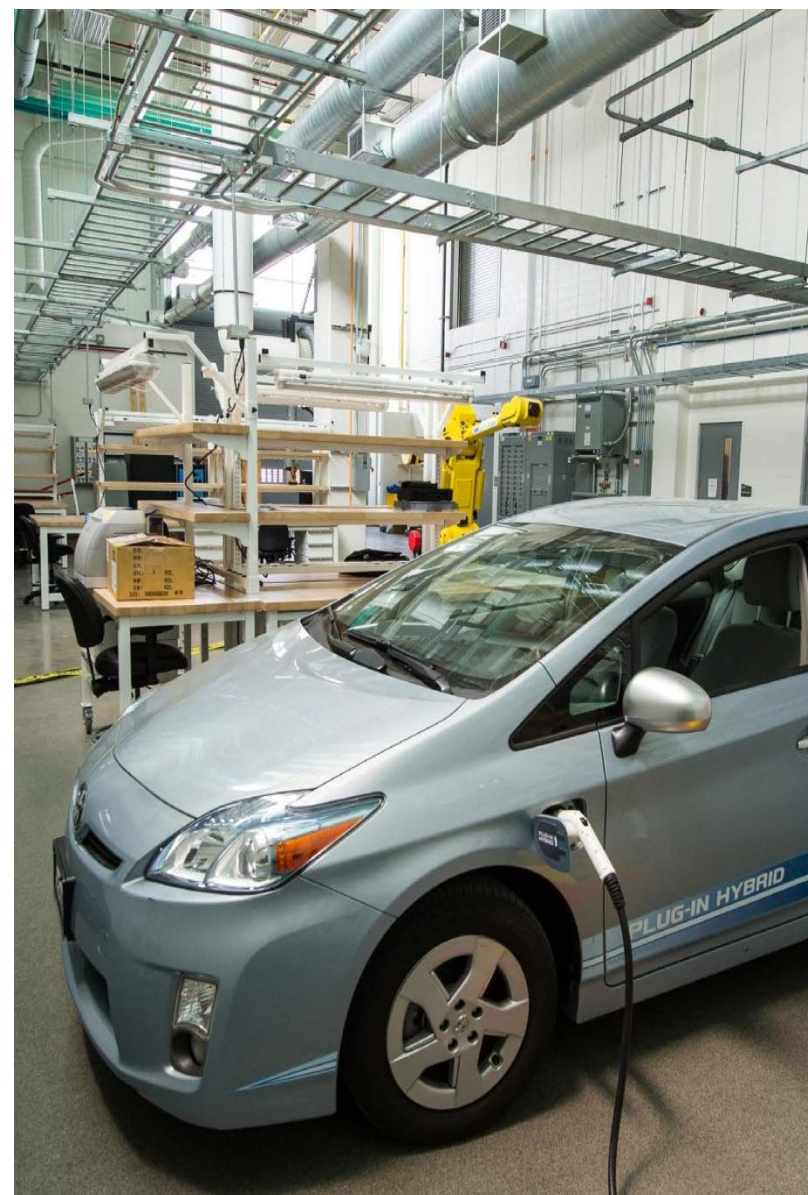
Electrical distribution system impacts

R&D STRATEGY

Collect data and conduct simulations to guide future experiments and projects that aid in the deployment of plug-in electric vehicles (PHEVs).

IMPACT

Correlation of individual vehicle power quality attributes to a system of PHEVs on a distribution network.



TECHNOLOGY ADDRESSED

Molten Salt Heat Transfer Fluid

R&D STRATEGY

Provide reliable thermophysical property data over a temperature range for 2 different mixtures of salts. The two salts listed below are to be tested, along with some commonly accepted and previously tested characteristics.

IMPACT

Integrated thermal storage technologies with concentrated solar.



ABENGOA

Innovative technology solutions for sustainability

TECHNOLOGY ADDRESSED

Advance microgrid technology for remote outback applications. 'Plug and play' discovery of components in a microgrid and optimization of energy use when incorporating distributed generation from solar.

R&D STRATEGY

Prototype testing of the microgrid controller to test the hardware's ability to manage the output power of a diesel generator in the presence of a load bank and solar simulator.

IMPACT

By simplifying the process of implementing, expanding and operating solar hybrid systems, this technology will assist system developers, owners and operators and help maximize the contribution of solar energy in these systems.



TECHNOLOGY ADDRESSED

Advanced Inverter SmartGrid features

R&D STRATEGY

Loop the SGI-500 utility-scale photovoltaic inverter to ESIF's hardware-in-the-loop capability and test its controls and functionality at full power in a real-world simulated environment.

IMPACT

Increase the speed of response to grid emergencies and improve grid power reliability and quality.



Innovation through Integration

....individual clean energy technologies are now coming together under the integrated approach of energy systems integration...



Solar's Time has Arrived...



"If you sit on the porch with the big dogs, and occasionally bark like a big dog, the world will view you as a big dog."

- Professor Richard Tapia



NATIONAL RENEWABLE ENERGY LABORATORY

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